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(54) Carrier phase recovery for an adaptive equalizer

Rückwinnung der Trägerphase für einen adaptiven Entzerrer

Récupérateur de la phase de la porteuse pour un égalisateur adaptatif

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- **IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS vol. SAC-5, no. 3, April 1987, NEW YORK US pages 466 - 475 BACCETTI B. ET AL.: 'Full Digital Adaptive Equalization in 64-QAM Radio Systems'**
- **IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS vol. SAC-5, no. 3, April 1987, NEW YORK US pages 349 - 356 CHAMBERLIN J. W. ET AL.: 'Design and Field Test of a 256-QAM DIV Modem'**
- **IEEE TRANSACTIONS ON COMMUNICATIONS vol. 30, no. 10, October 1982, pages 2385 - 2390 MATSUO Y. ET AL.: 'Carrier Recovery Systems for Arbitrarily Mapped APK Signals'**
- **IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS - ICC'76, 14-16 JUNE 1976, PHILADELPHIA, PENNSYLVANIA, US vol. 3, pages 48-7 - 48-12 LOGAN H. L. ET AL.: 'A MOS/LSI Multiple-Configuration 9600 BPS Data Modem'**

Description

The present invention relates to digital communications, and more particularly to a method and apparatus for recovering carrier phase in an adaptive equalizer without the use of phase rotation or de-rotation.

Digital data, for example digitized video for use in broadcasting high definition television (HDTV) signals, can be transmitted over terrestrial very high frequency (VHF) or ultra high frequency (UHF) analog channels for communication to end users. Analog channels deliver corrupted and transformed versions of their input waveforms. Corruption of the waveform, usually statistical, may be additive and/or multiplicative, because of possible background thermal noise, impulse noise, and fades. Transformations performed by the channel are frequency translation, nonlinear or harmonic distortion, and time dispersion.

In order to communicate digital data via an analog channel, the data is modulated using, for example, a form of pulse amplitude modulation (PAM). Typically, quadrature amplitude modulation (QAM) is used to increase the amount of data that can be transmitted within an available channel bandwidth. QAM is a form of PAM in which a plurality of bits of information are transmitted together in a pattern referred to as a "constellation", which can contain, for example, sixteen or thirty-two points.

In pulse amplitude modulation, each signal is a pulse whose amplitude level is determined by a transmitted symbol. In 16-QAM, symbol amplitudes of -3, -1, 1 and 3 in each quadrature channel are typically used. In bandwidth efficient digital communication systems, the effect of each symbol transmitted over a time-dispersive channel extends beyond the time interval used to represent that symbol. The distortion caused by the resulting overlap of received symbols is called intersymbol interference (ISI). This distortion has been one of the major obstacles to reliable high speed data transmission over low background noise channels of limited bandwidth. A device known as an "equalizer" is used to deal with the ISI problem.

In order to reduce the intersymbol interference introduced by a communication channel, rather precise equalization is required. Furthermore, the channel characteristics are typically not known beforehand. Thus, it is common to design and use a compromise (or a statistical) equalizer that compensates for the average of the range of expected channel amplitude and delay characteristics. A least mean square (LMS) error adaptive filtering scheme has been in common use as an adaptive equalization algorithm for over 20 years. This algorithm is described in B. Widrow and M. E. Hoff, Jr., "Adaptive Switching Circuits" in IRE Wescon Conv. Rec., Part 4, pp. 96-104, Aug. 1960. The use of the LMS algorithm in an adaptive equalizer to reduce intersymbol interference is discussed in S. U. H. Qureshi, "Adaptive Equalization", Proc. IEEE, Vol. 73, No. 9, pp. 1349-1387, September 1987.

In an LMS equalizer, the equalizer filter coefficients are chosen to minimize the mean square error, i.e., the sum of squares of all the ISI terms plus the noise power at the output of the equalizer. Therefore, the LMS equalizer maximizes the signal-to-distortion ratio at its output within the constraints of the equalizer time span and the delay through the equalizer. Before regular data transmission begins, automatic synthesis of the LMS equalizer for unknown channels may be carried out during a training period. This generally involves the iterative solution of a set of simultaneous equations. During the training period, a known signal is transmitted and a synchronized version of the signal is generated in the receiver to acquire information about the channel characteristics. The training signal may consist of periodic isolated pulses or a continuous sequence with a broad, uniform spectrum such as a widely known maximum length shift register or pseudo-noise sequence.

An important aspect of equalizer performance is its convergence, which is generally measured by the amount of time in symbol periods required for the error variance in the equalizer to settle at a minimum level, which is ideally zero. In order to obtain the most efficient operation for a data receiver, the equalizer convergence time must be minimized.

After any initial training period, the coefficients of an adaptive equalizer may be continually adjusted in a decision directed manner. In this mode, the error signal is derived from the final receiver estimate (not necessarily correct) of the transmitted sequence. In normal operation, the receiver decisions are correct with high probability, so that the error estimates are correct often enough to allow the adaptive equalizer to maintain precise equalization. Moreover, a decision directed adaptive equalizer can track slow variations in the channel characteristics or linear perturbations in the receiver front end, such as slow jitter in the sampler phase.

Many transmission systems employ modulation schemes that are constructed with complex signal sets. In other words, the signals are viewed as vectors in the complex plane, with the real axis called the inphase (I) channel and the imaginary axis called the quadrature (Q) channel. Consequently, when these signals are subjected to channel distortion and receiver impairments, cross talk between the I and Q channels occurs, requiring a complex adaptive equalizer. In this case, the equalizer's coefficients will be complex valued. If, as noted above, the channel distortion is unknown by the receiver, then the coefficients must be adjusted after the system has been in operation to cancel the channel distortion. The term "adaptive" in a complex adaptive equalizer signifies the ongoing adjustment of the coefficients.

In many practical transmission systems, some method must be provided to derive a reference signal at the receiver's demodulator that is phase coherent with the received signal. Such coherent demodulators are used to demodulate signals containing information

in their phase. For example, in binary phase shift keying (BPSK), modulation of a digital "one" is represented by a phase of zero degrees and modulation of a "zero" is represented by a phase of 180 degrees in the modulated signal. Data modulated using QAM techniques is demodulated on the basis of similar, although more complicated, phase relationships. Thus, demodulators for such data rely on a reference signal that must be synchronized in phase with the data carrier. This process is known as carrier phase recovery (CPR).

A phase locked loop (PLL) is a common and well known method used to recover the carrier in signal demodulators. When used in such applications, the PLL is sometimes referred to as a carrier recovery loop (CRL). When an adaptive equalizer is employed, it has been common practice to locate the CRL after the equalizer in the receiver. A free running oscillator is used to translate the input signal frequency to baseband, and a phase rotator is required to recover the carrier phase. In addition, a phase de-rotator is required in the adaptive equalizer to provide a correctly phased error signal for use in updating the filter coefficients. The requirement for a phase rotator and de-rotator complicates the receiver design, and adds expense to the receiver circuitry.

IEEE Jornal on Selected Areas in Communications, Vol. SAC-5, No. 3, April 1987, New York, NY, US, pages 349 - 356, Chamberlin J.W. et al.: "Design and Field Test of a 256-QAM DIV Modem"in particular fig. 2 thereof discloses a demodulator with a carrier recovery loop in which an adaptive equalizer is inserted.

The demodulator comprises four principal control loops which are carrier recovery loop, adaptive equalizer, digital AGC and symbol timing recovery. Each control loop has an initial acquisition and a tracking mode.

All four principal control loops are operated in a sequential manner.

In addition it is disclosed that if the phase or amplitude of the carrier being tracked by the carrier recovery loop suddenly and significantly changes all four of the loops will revert to their acquisition modes and acquisition will then be processed in the four loops in a sequential manner.

IEEE Transactions on Communications, Vol. COM-30, No. 10, October 1982, pages 2385 - 2390, Matsuo Y. et al.: "Carrier Recovery Systems for Arbitrarily Mapped APK Signals" deal with carrier phase recovery and discloses switching from an acquisition to a tracking mode in the carrier recovery process.

IEEE Journal on Selected Areas in Communications, Vol. SAC-5, No. 3, April 1987, New York, NY, US, pages 466 - 475, Baccetti B. et al.: "Full Digital Adaptive Equalization in 64-QAM Radio Systems" discloses a digital implementation of an adaptive equalizer for a 64 QAM system. The adaptive equalizer uses a blind equalization algorithm for acquisition and a least mean square error algorithm for tracking.

It is the object of the present invention to provide a method for adaptively equalizing data signals and an equalizing system for a communications receiver with improved characteristics.

According to the present invention this object is solved by a method for adaptively equalizing data signals in a communications receiver, said method comprising.

demodulation of an unequalized data signal by using a carrier recovery loop and
filtering said demodulated data signal in an adaptive equalizer by using adaptive filter coefficients
said filtering occuring within said carrier recovery loop
updating said adaptive filter coefficients by using error signals derived from a first algorithm or by using error signals derived from a second more efficient algorithm
wherein said first algorithm updates said adaptive filter coefficients independently of carrier phase recovery,
during carrier phase recovery said adaptive filter coefficients are updated by using error signals derived from said first algorithm,
a carrier lock signal is generated when a carrier phase error of a filtered signal output of said adaptive equalizer reaches a threshold value indicative of carrier phase recovery
and said second coefficient update algorithm is selected instead of said first coefficient update algorithm in response to said carrier lock signal.

Further advantageous embodiments are subject matter of claims 2 to 8 .

The object is further solved by an equalizing system for a communications receiver, said system comprising

a carrier recovery loop in which an unequalized data signal is demodulated
and an adaptive equalizer for filtering said demodulated data signal by using adaptive filter coefficients
said adaptive equalizer being located within said carrier recovery loop
said adaptive equalizer updating said adaptive filter coefficients by using error signals derived from a first algorithm or by using error signals derived from a second more efficient algorithm instead of said first coefficients update algorithm

wherein

said first algorithm updates said adaptive filter coefficients independently of carrier phase recovery,
said adaptive equalizer is updating said adaptive filter coefficients during carrier phase recovery by using error signals derived from said first algorithm,
a lock generator is provided for generating a carrier lock signal when a carrier phase error of a filtered

signal output from said adaptive equalizer reaches a threshold value indicative of carrier phase recovery

and that said adaptive equalizer selects said second coefficient update algorithm instead of said first coefficient update algorithm in response to said carrier lock signal.

Further advantageous embodiments of this solution are subject matter of claims 10 to 22.

According to the inventive concept a method for recovering carrier phase in systems employing adaptive equalization without the need for phase rotation and derotation hardware is provided.

Further an adaptive equalizer for a communications receiver that can initially adjust the equalizer coefficients in the absence of carrier phase recovery, thereby reducing the acquisition time of the system is provided.

Reduction of the system complexitiy by using self-recovering equalization algorithms that do not require a training sequence is a further advantage. Such a system is able to commence equalization without waiting for carrier recovery to occur.

In accordance with one embodiment of the present invention, a method is provided for adaptively equalizing data signals in a communications receiver. An unequalized data signal is demodulated. The demodulated data signal is filtered in an adaptive equalizer that initially updates adaptive filter coefficients using error signals derived from a first algorithm. A carrier lock signal is generated when a phase error of a filtered signal output from the adaptive equalizer reaches a threshold value. The adaptive filter coefficients are updated in the adaptive equalizer using error signals derived from a second algorithm instead of the first algorithm in response to the carrier lock signal.

In a preferred embodiment, the phase error is monitored during the operation of the adaptive equalizer, and the first algorithm takes over if it is determined during the monitoring step that the phase error no longer meets the threshold. Advantageously, the first algorithm will be a self-recovering equalization algorithm, such as a constant modulus algorithm. The second algorithm is advantageously a decision directed algorithm.

The phase error threshold is reached when at least a minimum percentage of samples of the filtered signal taken over time fall within a predetermined range. In an embodiment where the demodulated data signal comprises coordinates representing an N-bit constellation pattern for a demodulated N-bit quadrature amplitude modulated signal, the range can comprise a plurality of separate fixed areas, each area enclosing one of the constellation points. The separate fixed areas can comprise, for example, an ellipse surrounding a constellation point. In an illustrated embodiment, the ellipse is aligned with a corresponding radius extending from an origin of the constellation pattern to the constellation point the ellipse surrounds.

An adaptive equalizer for a communications receiver in accordance with another embodiment of the present invention comprises means for demodulating an unequalized data signal. An equalizer loop contains a filter coupled to receive demodulated data from the demodulating means, an error signal generator coupled to receive filtered data from the filter, and means responsive to error signals from the error signal generator for updating coefficients for input to the filter. A carrier recovery loop comprises a phase detector coupled to receive the filtered data and provide a first phase error signal for controlling the demodulator. Means, coupled to receive a second phase error signal from the phase detector, generate a carrier lock signal when the second phase error -signal meets a threshold. The error signal generator is responsive to the carrier lock signal for generating error signals from a first algorithm when the second phase error signal fails to meet the threshold and for generating error signals from a second algorithm when the second phase error signal meets the threshold.

The error signal generator can comprise, for example, a memory storing a first set of error signals computed using the first algorithm and a second set of error signals computed using the second algorithm. In such an embodiment, the filtered data and the carrier lock signal are used to address the memory to output error signals.

Preferably, the first algorithm will be a self-recovering equalization algorithm, such as a constant modulus algorithm. The second algorithm can be a decision directed algorithm. The phase error threshold will be met when at least a minimum percentage of samples of the filtered signal taken over time fall within a predetermined range. In an illustrated embodiment, the demodulated data signal comprises coordinates representing an N-bit constellation pattern for a demodulated N-bit quadrature amplitude modulated signal. The predetermined range for determining whether the threshold is met comprises a plurality of separate fixed areas, each enclosing one of the constellation points. Each of the separate fixed areas can comprise an ellipse surrounding a constellation point, each ellipse being aligned with a corresponding radius extending from an origin of the constellation pattern to the constellation point the ellipse surrounds.

The present invention also provides an adaptive equalizer for a communications receiver wherein an adaptive filter is provided for filtering unequalized data representative of coordinates in a constellation pattern. An error signal generator converts the filtered data from the filter to error signals based on a first or second algorithm. Means are coupled to receive error signals output from the error signal generator for updating coefficients for the adaptive filter. A phase detector converts filtered data from the filter to phase error signals. Means responsive to the phase error signals control the error signal generator to provide error signals according to the

first algorithm when a phase error represented by the phase error signals is above a predetermined threshold. Error signals are provided according to the second algorithm when the phase error is below the predetermined threshold.

The error signal generator of the adaptive equalizer can comprise a look-up table containing error signal data computed under the first and second algorithms. The look-up table is addressed by the filter data and the control means to output the error signals. The phase detector can also comprise a look-up table. This table would contain phase error data and be addressed by the filter data to output the phase error signals.

Further features and advantages of the present invention are disclosed in the detailed specification.

The drawings disclose the following:

Figure 1 is a block diagram of a prior art communications receiver illustrating an adaptive equalizer followed by a carrier recovery loop including a phase rotator;

Figure 2 is a block diagram illustrating a communication system incorporating an adaptive equalizer in accordance with the present invention;

Figure 3 is a block diagram illustrating the adaptive equalizer of the present invention in greater detail;

Figure 4 provides three scatter plots illustrating the output of the equalizer of the present invention at different points in time;

Figure 5 is a graph illustrating the mean square error over time of an adaptive equalizer in accordance with the present invention;

Figure 6 is a graph illustrating a carrier lock signal provided to the adaptive equalizer of the present invention; and

Figure 7 is a graphical representation of a constellation pattern for sixteen-bit QAM data, illustrating fixed elliptical areas used to determine when a phase error threshold has been met.

Figure 1 illustrates a prior art data transmission/reception system in which the communication receiver includes an adaptive equalizer followed by a carrier recovery loop using a phase rotator. Modulated digital data is input to a transmitter 12 Via an input terminal 10 in a conventional manner. The transmitter broadcasts the data via a channel 14 that introduces amplitude and/or delay (phase) distortion. When the modulated data comprises multilevel pulse amplitude modulated data, such as QAM data, intersymbol interference takes place within the channel. An adaptive equalizer 20 is provided in the receiver to compensate for the intersymbol interference. The equalizer is essentially a filter with coefficients chosen to cancel the effects of the channel distortion.

The data received from channel 14 is demodulated at the receiver in a demodulator 16 that is controlled by a free running oscillator 18. In the illustrated embodiment, a quadrature demodulator is used to receive complex QAM data. The received data is demodulated to recover the real and imaginary complex components. These components are input to an adaptive filter 24 of adaptive equalizer 20. The filtered output from filter 24 is input to an independent carrier recovery loop 22. A phase rotator 26 in the carrier recovery loop shifts the phase of the filtered signals by an estimate of the phase error between a transmitted signal and a received signal. A phase detector 30 coupled to the output of phase rotator 26 generates an error signal indicative of the difference between the estimated phase shift and the actual shift introduced by channel 14. The error signal is filtered by a loop filter 32 and used as an input to a numerically controlled oscillator 34 to adjust phase rotator 26 in a manner that attempts to reduce the error signal to zero.

The output of phase rotator 26 is also coupled to an error signal generator 36 in the adaptive equalizer. An error signal is generated indicative of the amount of intersymbol interference contained in the filtered, demodulated input signals. The phase of the error signal is derotated in a phase de-rotator 38, and input to a coefficients update calculation circuit 40 for use in updating the adaptive filter coefficients. In this manner, the intersymbol interference is reduced over time so that the transmitted data can be accurately decoded by a conventional decoder 28.

A problem with the prior art structure illustrated in Figure 1 is that it is complicated and expensive, in particular because of the need to provide a phase rotator in the carrier recovery loop and a phase de-rotator in the adaptive equalizer. A typical phase rotator requires four multiplies and two additions to provide the desired phase correction. Similar operations are required in the de-rotator. Therefore, by eliminating the phase rotator and phase de-rotator, it is possible to save the hardware that performs eight multiplies and four adds.

The present invention provides an adaptive equalizer that eliminates the phase rotation and phase derotation components by locating the equalizer inside of the carrier recovery loop. This is illustrated in general terms in Figure 2. As with the prior art, modulated data is input to a transmitter 52 via an input terminal 50. The data is broadcast over a channel 54, that introduces the distortions which cause intersymbol interference in the multilevel modulated data. A communications receiver in accordance with the invention uses a carrier recovery loop 56 that incorporates a demodulator 58, adaptive equalizer 60, and carrier recovery circuit 62. In the illustrated embodiment, 16-QAM data is received, and demodulator 58 is a quadrature demodulator that recovers the real and imaginary complex components from the 16-QAM data. Since complex data is provided, adaptive equalizer 60 is a complex adaptive equalizer. Carrier recovery circuit 62 provides a phase error signal to demodulator 58 and also provides a "carrier lock" signal to adaptive equalizer 60. The carrier lock signal, as dis-

cussed in greater detail below, is used to select between an intersymbol interference error signal derived from a first, self-recovering equalization algorithm such as the Constant Modulus Algorithm and a second decision directed algorithm for use in updating filter coefficients for the equalizer. A conventional decoder 64 is provided to recover individual data bits from the equalized channel data output from the adaptive equalizer.

Figure 3 illustrates the carrier recovery loop 56 in greater detail. A phase locked loop, consisting of a phase detector 76, loop filter 80, and voltage controlled oscillator (VCO) 82 surrounds adaptive equalizer 60. The adaptive equalizer uses two least mean square (LMS) algorithms to adjust (i.e., update) the coefficients used by an adaptive filter 70. In the illustrated embodiment, the first LMS algorithm used is the Constant Modulus Algorithm (CMA) which is well known in the art and described, for example, in D. N. Godard, "Self-Recovering Equalization and Carrier Tracking in Two-Dimensional Data Communication Systems", IEEE Trans. on Commun., Vol. COM-28, pp. 1867-1875, November 1980. The second LMS algorithm used by the adaptive equalizer is a decision directed algorithm (DDA). The two coefficient update algorithms differ only in the way the error signal used to update the coefficients is generated. The LMS algorithm is given by:

$$C(k+1)=C(k)+\Delta E(k)X^*(k)$$

where C(k) is the complex vector of coefficients, X(k) is the complex vector of delayed data, * means complex conjugate, E(k) is the complex error signal, and Δ is a scale factor. For the CMA the error signal is given by:

$$E(k)_{cma}=\{|y(k)|^2-R_2\}y(k)$$

where y(k) is the complex output of the adaptive equalizer and R_2 is a constant. For the DDA the error signal is given by:

$$E(k)_{dda}=y'(k)-y(k)$$

where y'(k) is the "signal decision". The signal decision is based on a determination as to which constellation point a received coordinate set is closest to. Upon finding the closest constellation point to the received data point, a decision is made that the received data point corresponds to the nearest constellation point.

Adaptive equalizer 60 comprises an inner loop including error signal generator 72, coefficients update calculation circuitry 74, and adaptive filter 70. The error signal generator receives the filtered channel data from adaptive filter 70, determines the error in the filtered data (i.e., the difference between the filtered data and an ideal constellation pattern), and outputs an error signal indicative thereof for use by the coefficients update calculation circuit. In response to the error signal, updated coefficients are provided to the adaptive filter 70, so that after a period of time the equalized channel data output from filter 70 will be restored to a condition from which the transmitted data can be recovered by a conventional decoder.

In accordance with the present invention, the CMA algorithm, which is a self-recovering equalization algorithm (also known as a blind equalization algorithm) that does not require initialization with a training sequence, is first used to adjust the coefficients until the channel data is sufficiently equalized so that carrier phase recovery can be achieved. An important aspect of the CMA algorithm for purposes of the present invention is that it is independent of carrier phase recovery. The CMA algorithm provides the initial equalization necessary for the outer carrier recovery loop (phase detector 76, loop filter 80, and VCO 82) to be operational.

Like error signal generator 72, phase detector 76 also monitors the filtered data from adaptive filter 70. It determines the phase error between the filtered data and the ideal constellation pattern for the modulation scheme used. The phase error is quantized in a well known manner to provide a first phase error signal on line 77 that is processed for use by demodulator 58 in recovering the carrier phase. An example of such a quantizing scheme is provided in A. Leclert and P. Vandamme, "Universal Carrier Recovery Loop for QASK and PSK Signal Sets," IEEE Trans. on Communications, Vol. COM-31, No. 1, Jan. 1983, pp. 130-136. The operation of the phase detector is explained in greater detail below. For the present, it is noted that one output of the phase detector is coupled to loop filter 80 and VCO 82 in a conventional manner to control quadrature demodulator 58 based on the detected phase error. The operation of the carrier recovery loop will drive demodulator 58 to a point where the phase error is minimized in view of the feedback provided by the loop.

Phase detector 76 also quantizes the phase error using a second quantizing scheme to produce a second phase error signal on line 75 that is input to a carrier lock generator 78 in accordance with the present invention. Although the quantizing schemes used to generate the first and second phase error signals can be the same, it is preferable to use different schemes, wherein the scheme used to generate the first phase error signal is selected for its ease of implementation and to reduce the possibility of false lock points for QAM. The second quantization scheme is selected to provide an early indication as to when the CMA algorithm has converged. Such a quantization scheme is described below in connection with Figure 7.

Generator 78 uses a sliding average technique to determine when the phase error drops below a predetermined threshold. When the threshold is met, the phase of the filtered data signal will be sufficiently close to that of the transmitted signal that accurate data re-

covery can commence. At this point, the CMA algorithm will have served its function of self-recovery, and the DDA algorithm can be substituted to provide more efficient equalizer operation. Thus, lock generator 78 outputs a carrier lock signal to error signal generator 72 when the threshold is met. In response to the carrier lock signal, error signal generator 72 switches from the CMA method of calculating the error signals to the DDA method. In the event that the threshold is no longer met at some time during the operation of the equalizer, the carrier lock signal will turn off, and the error signal generator will switch back to the CMA algorithm. Thus, the system will automatically operate in the CMA mode when necessary, and switch over to the DDA mode as soon as the phase error has been reduced below the predetermined threshold value.

In a preferred embodiment, error signal generator 72 and phase detector 76 both comprise programmable read-only memory (PROM) devices to enable high speed operation of the equalizer, e.g., at symbol rates on the order of 5 MHz. The PROM used for the error signal generator will contain two sets of values. One set will comprise error signal values computed using the CMA algorithm. The other set will comprise error signal values computed using the DDA method. The filtered data input to the error signal generator PROM from adaptive filter 70 is used to address the memory and output the error signals that have been precomputed for the specific filtered data values. The carrier lock signal input to the error signal generator PROM provides an additional address signal to select between the first set of values (CMA) or second set of values (DDA) depending on whether the phase error threshold has been met.

The phase detector PROM stores two sets of precomputed phase error values corresponding to the possible filtered data values output from adaptive filter 70. One set of phase error values represents quantized values according to the first quantizing scheme discussed above, and the other set of phase error values corresponds to the quantized values provided by the second quantizing scheme discussed above and explained in further detail in connection with Figure 7. The filtered data values are used to address the phase detector PROM, and output the first and second phase error signals associated with the particular filtered data values. Lock generator 78 computes a sliding average of the second phase error signals based on a relatively large number of samples. For example, lock generator 78 can comprise an accumulator that accumulates the error signals output from phase detector 76 for one thousand samples of the filtered data output from filter 70. In the event a particular data coordinate set output from adaptive filter 70 represents a point that falls within a predetermined area of the constellation pattern, the phase detector 76 can output a second phase error signal that is, e.g., a "+1". On the other hand, if the data coordinates represent a point falling outside of the predetermined area in the constellation pattern, a "-1" can be output as the second phase error signal. If the last one thousand error signal samples input to lock generator 78 have an average value of, say, zero or above, lock generator 78 will output the carrier lock signal to actuate error signal generator to switch from the CMA mode to the DDA mode.

Figure 7 illustrates a preferred embodiment of the phase error detection scheme (i.e., the second quantization scheme) used to generate the second phase error signals that are output from phase detector 76. In the illustrated embodiment, 16-QAM is used to transmit the data. Accordingly, constellation pattern 120 includes sixteen points. Each point is surrounded by a predetermined elliptical area, such as areas 126 and 132 illustrated. Ellipse 126 surrounds constellation point 122, and is aligned with a corresponding radius 124 extending from the origin of the constellation pattern to the constellation point 122. Similarly, ellipse 132 surrounds constellation point 128, and is aligned with a radius 130 extending from the constellation pattern origin to point 128. Similarly aligned elliptical areas (not shown) are defined around each of the other points of the constellation pattern.

In the event a received data point falls within one of the ellipses, the phase detector PROM 76 will output an error signal having the amplitude "1". In the event that a received data point does not fall within any of the ellipses defined around the constellation points, a "-1" error signal will be output from phase detector 76. Once a certain percentage of "1" error signals are received, lock generator 78 will declare a lock and output the carrier lock signal to error signal generator 72.

As an example, in a 16-QAM system wherein elliptical areas are used as shown in Figure 7, the ratio of the major axis of the ellipse to the minor axis of the ellipse can be chosen to be 29:20 on a grid having axes running from -128 to +128, with 0-128 corresponding to signal amplitudes of 0-4. The ratio of the area inside the ellipses to the total area can be approximately 40%. A lock is declared when 50% of the incoming data falls within the 40% of the total area defined by the ellipses. It is noted that the specific areas and percentages chosen will vary for different applications. If the areas chosen are too big, false locks will occur. Conversely, if the areas chosen are too small, the system will not lock as soon as it should, and may not lock at all. It is further noted that the shapes of the areas surrounding the constellation points do not have to be ellipses. Other shapes such as circles or squares can be defined.

Computer simulation of the invention has verified its effectiveness in improving the performance of a complex adaptive equalizer. In the simulation, the transmission system was 16-QAM at a symbol rate of 5 MHz, with additive white Gaussian noise (AWGN) and multipath distortion. The carrier was offset by 500 Hz in frequency and 45 degrees in phase. The carrier-to-noise ratio (C/N) was 30 dB, and the multipath had a reflected ray delayed by 10 microseconds, which was down -6 dB

from the direct ray. A 256 complex tap fractional spaced equalizer was used. The PLL noise bandwidth was set at 50 KHz with a damping factor of 2 (at C/N = 30 dB). The simulation results are illustrated in Figures 4, 5 and 6.

Figure 4 illustrates the scatter plots of the simulated data at the output of the adaptive equalizer at various times. Scatter plot 90 shows the data as initially received. Scatter plot 92 shows the data just after the CMA mode of operation ends, and the DDA starts. Scatter plot 94 illustrates the output of the equalizer at the end of the simulation. As the scatter plots of Figure 4 illustrate, the combination of the initial CMA mode and carrier recovery PLL work to clean up the scatter plot, so that the DDA mode of operation can take over.

Figure 5 shows the mean square error (MSE) generally designated 96 out of the adaptive equalizer. Figure 6 illustrates the carrier lock signal, generally designated 104, provided by the lock generator. Lock occurred at the zero crossing 110 after approximately 10,000 symbols were received. As indicated at 108, the lock signal was steady once it was generated. As indicated in Figure 5, convergence under the CMA mode of operation, as indicated at 98, was acceptable. After lock occurred at 102, the convergence was improved by use of the DDA mode of operation.

It should now be appreciated that the present invention provides a method and apparatus for recovering carrier phase in systems employing adaptive equalization, without the use of a phase rotator or phase de-rotator. This is achieved by locating the adaptive equalizer inside of the carrier recovery loop. A blind equalization algorithm, such as CMA is used to initially adjust the equalizer coefficients in the absence of carrier phase recovery, reducing the acquisition time of the system. This occurs without the use of an equalizer training sequence, which reduces the complexity of the system design. A carrier lock signal is used to determine when to switch from the blind equalization algorithm to a decision directed algorithm to complete the convergence of the adaptive equalizer and phase locked loop. Thus, it is not necessary to wait for carrier recovery to occur while equalizing the received data.

Although the invention has been described in connection with a preferred embodiment thereof, those skilled in the art will appreciate that numerous adaptations and modifications may be made thereto, without departing from the scope of the invention as set forth in the claims.

Claims

1. A method for adaptively equalizing data signals in a communications receiver, said method comprising

   demodulation of an unequalized data signal by using a carrier recovery loop (56) and
   filtering said demodulated data signal in an adaptive equalizer (60) by using adaptive filter coefficients
   said filtering occurring within said carrier recovery loop (56)
   updating said adaptive filter coefficients by using error signals derived from a first algorithm or by using error signals derived from a second more efficient algorithm

   characterized in that

   said first algorithm updates said adaptive filter coefficients independently of carrier phase recovery,
   during carrier phase recovery said adaptive filter coefficients are updated by using error signals derived from said first algorithm,
   a carrier lock signal is generated when a carrier phase error of a filtered signal output of said adaptive equalizer (60) reaches a threshold value indicative of carrier phase recovery
   and that said second coefficient update algorithm is selected instead of said first coefficient update algorithm in response to said carrier lock signal.

2. A method in accordance with claim 1 comprising the further steps of:

   monitoring said phase error during the operation of said adaptive equalizer (60); and
   returning to said first algorithm if it is determined during said monitoring step that said phase error no longer meets said threshold.

3. A method in accordance with claim 1 or 2 wherein said first algorithm is a self recovering equalization algorithm.

4. A method in accordance with claim 3 wherein said self recovering equalization algorithm is a constant modulus algorithm.

5. A method in accordance with one of the preceding claims wherein said second algorithm is a decision directed algorithm.

6. A method in accordance with one of the preceding claims wherein said threshold value is reached when at least a minimum percentage of samples of said filtered signal taken over time fall within a predetermined range.

7. A method in accordance with claim 6 wherein:

   said demodulated data signal comprises coor-

dinates representing an N-point constellation pattern for a demodulated N-bit quadrature amplitude modulated signal; and
said range comprises a plurality of separate fixed areas, each area enclosing one of the points in said constellation pattern.

8. A method in accordance with claim 7 wherein each of said separate fixed areas comprises an ellipse surrounding one of the points in said constellation pattem, each ellipse being aligned with a corresponding radius extending from an origin of said constellation pattern to the point the ellipse surrounds.

9. An equalizing system for a communications receiver, said system comprising

a carrier recovery loop (56) in which an unequalized data signal is demodulated
and an adaptive equalizer (60) for filtering said demodulated data signal by using adaptive filter coefficients
said adaptive equalizer (60) being located within said carrier recovery loop (56)
said adaptive equalizer (60) updating said adaptive filter coefficients by using error signals derived from a first algorithm or by using error signals derived from a second more efficient algorithm instead of said first coefficients update algorithm

characterized in that

said first algorithm updates said adaptive filter coefficients independently of carrier phase recovery,
said adaptive equalizer (60) is updating said adaptive filter coefficients during carrier phase recovery by using error signals derived from said first algorithm,
a lock generator (78) is provided for generating a carrier lock signal when a carrier phase error of a filtered signal output from said adaptive equalizer (60) reaches a threshold value indicative of carrier phase recovery
and that said adaptive equalizer (60) selects said second coefficient update algorithm instead of said first coefficient update algorithm in response to said carrier lock signal.

10. A system in accordance with claim 9 wherein
said adaptive equalizer (60) comprises an adaptive filter (70) and an error signal generator (72) coupled to receive filtered data from said adaptive filter (70) said error signal generator generating error signals in accordance with said first or second algorithm, and means (74) responsive to said error signals for updating said adaptive filter coefficients.

11. A system in accordance with claim 10, wherein

a carrier recovery loop comprises a demodulator (58) and a phase detector (76) coupled to receive said filtered signal output of said adaptive equalizer (60) and provide a first phase error signal for controlling said demodulator (58); and
said lock generator receives a second phase error signal from said phase detector (76), for generating said carrier lock signal when said second phase error signal meets a threshold.

12. A system in accordance with claim 9 wherein said error signal generator (72) comprises a memory storing a first set of error signals computed using said first algorithm and a second set of error signals computed using said second algorithm.

13. A system in accordance with claim 12 wherein said filtered data and said carrier lock signal are used to address said memory to output error signals.

14. A system in accordance with one of claims 9 to 13 wherein said first algorithm is a self recovering equalization algorithm.

15. A system in accordance with claim 14 wherein said self recovering equalization algorithm is a constant modulus algorithm.

16. A system in accordance with one of claims 9 to 15 wherein said second algorithm is a decision directed algorithm.

17. A system in accordance with one of claims 9 to 16 wherein said phase error threshold is met when at least a minimum percentage of samples of said filtered data taken over time fall within a predetermined range.

18. A system in accordance with claim 17 wherein:

said demodulated data signal comprises coordinates representing an N-point constellation pattern for a demodulated N-bit quadrature amplitude modulated signal; and
said range comprises a plurality of separate fixed areas, each enclosing one of the points in said constellation pattern.

19. A system in accordance with claim 16 wherein
each of said separate fixed areas comprises an ellipse surrounding one of the points in said constellation pattem, each ellipse being aligned with a corresponding radius extending from an origin of

said constellation pattern to the point the ellipse surrounds.

20. A system according to claim 9 comprising:

an adaptive filter (70) for filtering unequalized data representative of coordinates in a constellation pattern;
an error signal generator (72) for converting filtered data from said filter to error signals based on said first or second algorithm;
means (74) coupled to receive error signals output from said error signal generator (72) for updating coefficients for said adaptive filter (70);
a phase detector (76) for converting filtered data from said filter (70) to phase error signals; and
said lock generator (78) being responsive to said phase error signals for controlling said error signal generator (72) to provide error signals according to said first algorithm when a phase error represented by said phase error signals is above a predetermined threshold and to provide error signals according to said second algorithm when said phase error is below said predetermined threshold.

21. A system in accordance with claim 20 wherein said error signal generator (72) comprises a look up table containing error signal data computed under said first and second algorithms and addressed by said filtered data and said control means to output said error signals.

22. A system in accordance with claim 20 or 21 wherein said phase detector (76) comprises a look up table containing phase error data and addressed by said filtered data to output said phase error signals.

Patentansprüche

1. Verfahren zum adaptiven Entzerren von Datensignalen in einem Kommunikationsempfänger, wobei das Verfahren umfaßt

Demodulation eines nicht entzerrten Datensignals durch Verwendung einer Träger-Rückgewinnungsschleife (56) und

Filtern des demodulierten Datensignals in einem adaptiven Entzerrer (60) durch Verwendung von Adaptiv-Filter-Koeffizienten,

wobei das Filtern innerhalb der Träger-Rückgewinnungsschleife (56) erfolgt,

Aktualisieren der Adaptiv-Filter-Koeffizienten durch Verwendung von Fehlersignalen, welche aus einem ersten Algorithmus abgeleitet werden, oder durch Verwendung von Fehlersignalen, welche aus einem zweiten effizienteren Algorithmus abgeleitet werden,

dadurch gekennzeichnet,

daß der erste Algorithmus die Adaptiv-Filter-Koeffizienten unabhängig von der Trägerphasenrückgewinnung aktualisiert,

während der Trägerphasenrückgewinnung die Adaptiv-Filter-Koeffizienten durch Verwendung von Fehlersignalen, welche von dem ersten Algorithmus abgeleitet werden, aktualisiert werden,

ein Trägerkopplungssignal erzeugt wird, wenn ein Trägerphasenfehler eines gefilterten Signalausgangs des adaptiven Entzerrers (60) einen Schwellenwert erreicht, welcher bezeichnend ist für die Trägerphasenrückgewinnung,

und daß der zweite Koeffizienten-Aktualisierungs-Algorithmus anstatt des ersten Koeffizienten-Aktualisierungs-Algorithmus als Antwort auf das Trägerkopplungssignal ausgewählt wird.

2. Verfahren nach Anspruch 1, welches die weiteren Schritte umfaßt:

Überwachen des Phasenfehlers während des Betriebs des adaptiven Entzerrers (60); und

Rückkehr zu dem ersten Algorithmus, wenn es während dem ersten Überwachungsschritt ermittelt wird, daß der Phasenfehler nicht länger die Schwelle erreicht.

3. Verfahren nach Anspruch 1 oder 2, wobei der erste Algorithmus ein sich selbst wiederherstellender Entzerrungs-Algorithmus ist.

4. Verfahren nach Anspruch 3, wobei der sich selbst wiederherstellende Entzerrungs-Algorithmus ein Konstant-Modul-Algorithmus ist.

5. Verfahren nach einem der vorangehenden Ansprüche, wobei der zweite Algorithmus ein entscheidungsgerichteter Algorithmus ist.

6. Verfahren nach einem der vorangehenden Ansprüche, wobei der Schwellenwert erreicht wird, wenn mindestens ein Mindestprozentsatz von Proben des gefilterten Signals über die Zeit genommen in-

nerhalb einen vorbestimmten Bereich fällt.

7. Verfahren nach Anspruch 6, wobei:

   das demodulierte Datensignal Koordinaten umfaßt, die ein N-Punkt-Konstellationsmuster für ein N-Bit-Quadraturmoduliertes Signal repräsentieren; und

   wobei der Bereich eine Mehrzahl von getrennten festen Gebieten umfaßt, wobei jedes Gebiet einen der Punkte in dem Konstellationsmuster einschließt.

8. Verfahren nach Anspruch 7, wobei jedes der getrennten festen Gebiete eine Ellipse umfaßt, die einen der Punkte in dem Konstellationsmuster umgibt, wobei jede Ellipse mit einem zugehörigen Radius ausgerichtet ist von einem Ursprung des Konstellationsmusters zu dem Punkt, den die Ellipse umgibt.

9. Entzerrungssystem für einen Kommunikationsempfänger, wobei das System umfaßt:

   eine Trägerrückgewinnungsschleife (56), in der ein nicht entzerrtes Signal demoduliert wird

   und einen adaptiven Entzerrer (60) zum Filtern des demodulierten Datensignals durch Verwendung von Adaptiv-Filter-Koeffizienten,

   wobei der adaptive Entzerrer (60) innerhalb der Träger-rückgewinnungsschleife (56) angeordnet ist,

   wobei der adaptive Entzerrer (60) die Adaptiv-Filter-Koeffizienten durch Verwendung von Fehlersignalen, die aus einem ersten Algorithmus abgeleitet werden, oder durch Verwendung von Fehlersignalen, die aus einem zweiten effizienteren Algorithmus anstatt des ersten Koeffizienten-Aktualisierungs-Algorithmus abgeleitet werden, aktualisiert,

   dadurch gekennzeichnet,

   daß der erste Algorithmus die Adaptiv-Filter-Koeffizienten unabhängig von einer Trägerphasenrückgewinnung aktualisiert,

   wobei der adaptive Entzerrer (60) die Adaptiv-Filter-Koeffizienten während der Trägerphasenrückgewinnung durch Fehlersignale, welche aus dem ersten Algorithmus abgeleitet werden, aktualisiert,

   ein Kopplungsgenerator (78) vorgesehen ist zum Erzeugen eines Trägersperrsignals, wenn ein Trägerphasenfehler eines gefilterten Signalausgangs des adaptiven Entzerrers (60) einen Schwellenwert erreicht, der bezeichnend ist für die Trägerphasenrückgewinnung,

   und daß der adaptive Entzerrer (60) den zweiten Koeffizienten-Aktualisierungs-Algorithmus anstatt des ersten Koeffizienten-Aktualisierungs-Algorithmus auswählt als Antwort auf das Trägerkopplungssignal.

10. System nach Anspruch 9, wobei der adaptive Entzerrer (60) ein adaptives Filter (70) und einen Fehlersignalgenerator (72), welcher angekoppelt ist, um gefilterte Daten von dem adaptiven Filter (70) zu empfangen, wobei der Fehlersignalgenerator Fehlersignale gemäß dem ersten oder zweiten Algorithmus erzeugt, und Mittel (74), die auf die Fehlersignale zum Aktualisieren der Adaptiv-Filter-Koeffizienten ansprechen, umfaßt.

11. System nach Anspruch 10, wobei

   eine Trägerrückgewinnungsschleife einen Demodulator (58) und einen Phasendetektor (76) umfaßt, welcher angekoppelt ist, um den gefilterten Signalausgang des adaptiven Entzerrers (60) zu empfangen und ein erstes Phasenfehlersignal zum Steuern oder Regeln des Demodulators (58) bereitzustellen; und

   der Kopplungsgenerator empfängt ein zweites Phasenfehlersignal von dem Phasendetektor (76) zum Erzeugen des Trägerkopplungssignals, wenn das zweite Phasenfehlersignal eine Schwelle erreicht.

12. System nach Anspruch 9, wobei der Fehlersignalgenerator (72) einen Speicher umfaßt, welcher einen festen Satz von Fehlersignalen, die unter Verwendung des ersten Algorithmus berechnet werden, und einen zweiten Satz von Fehlersignalen, die unter Verwendung des zweiten Algorithmus berechnet werden speichert.

13. System nach Anspruch 12, wobei die gefilterten Daten und das Trägerkopplungssignal verwendet werden, den Speicher zu adressieren, um Fehlersignale auszugeben.

14. System nach einem der Ansprüche 9 bis 13, wobei der erste Algorithmus ein sich selbst wiederherstellender Entzerrungsalgorithmus ist.

15. System nach Anspruch 14, wobei der sich selbst wiederherstellende Algorithmus ein Konstant-Modul-Algorithmus ist.

16. System nach einem der Ansprüche 9 bis 15, wobei der zweite Algorithmus ein entscheidungsgerichteter Algorithmus ist.

17. System nach einem der Ansprüche 9 bis 16, wobei die Phasenfehlerschwelle erreicht ist, wenn mindestens ein Minimumprozentsatz von Proben der gefilterten Daten über die Zeit genommen innerhalb einen vorbestimmten Bereich fällt.

18. System nach Anspruch 17, wobei:

das demodulierte Datensignal umfaßt Koordinaten, die ein N-Punkt-Konstellationsmuster für ein demoduliertes N-Bit-Quadratur-amplitudenmoduliertes Signal repräsentieren; und

der Bereich umfaßt eine Mehrzahl von getrennten festen Gebieten, von denen jedes einen der Punkte in dem Konstellationsmuster einschließt.

19. System nach Anspruch 16, wobei jedes der getrennten festen Gebiete eine Ellipse umfaßt, die einen der Punkte in dem Konstellationsmuster umgibt, wobei jede Ellipse ausgerichtet mit einem zugehörigen Radius sich von einem Ursprung des Konstellationsmusters zu dem Punkt, den die Ellipse umgibt, erstreckt.

20. System nach Anspruch 9, welches umfaßt:

einen adaptiven Filter (70) zum Filtern nicht entzerrter Daten, welche repräsentativ sind für Koordinaten in einem Konstellationsmuster;

einen Fehlersignalgenerator (72) zum Konvertieren der gefilterten Daten von dem Filter zu Fehlersignalen auf Basis des ersten oder zweiten Algorithmus;

Mittel (74), die angekoppelt sind, um Fehlersignale zu empfangen, die von dem Fehlersignalgenerator (72) zum Aktualisieren von Koeffizienten des adaptiven Filters (70) ausgegeben werden;

einen Phasendetektor (76) zum Konvertieren von gefilterten Daten von dem Filter (70) zu Phasenfehlersignalen; und

wobei der Kopplungsgenerator (78) anspricht auf die Phasenfehlersignale zum Steuern oder Regeln des Fehlersignalgenerators (72), um Fehlersignale gemäß dem ersten Algorithmus bereitzustellen, wenn ein Phasenfehler, welcher durch Phasenfehlersignale repräsentiert ist, oberhalb einer vorbestimmten Schwelle liegt, und um Fehlersignale gemäß dem zweiten Algorithmus bereitzustellen, wenn der Phasenfehler unterhalb der vorbestimmten Schwelle ist.

21. System nach Anspruch 20, wobei der Fehlersignalgenerator (72) eine Nachschau-Tabelle umfaßt, welche Fehlersignaldaten enthält, die unter den ersten und zweiten Algorithmen berechnet werden und durch die gefilterten Daten und die Steuerungs- oder Regelungsmittel adressiert werden, um die Fehlersignale auszugeben.

22. System nach Anspruch 20 oder 21, wobei der Phasendetektor (76) eine Nachschau-Tabelle umfaßt, die Phasenfehlerdaten enthält und durch die gefilterten Daten adressiert wird, um die Phasenfehlersignale auszugeben.

Revendications

1. Procédé pour compenser de façon adaptative des signaux de données dans un récepteur de communications, le procédé comprenant:

une démodulation d'un signal de données non compensé, en utilisant une boucle de récupération de porteuse (56), et
un filtrage du signal de données démodulé, dans un égaliseur adaptatif (60), en utilisant des coefficients de filtre adaptatif,
le filtrage ayant lieu dans la boucle de récupération de porteuse (56),
une mise à jour des coefficients de filtre adaptatif en utilisant des signaux d'erreur dérivés d'un premier algorithme ou en utilisant des signaux d'erreur dérivés d'un second algorithme plus efficace,

caractérisé en ce que:

le premier algorithme met à jour, indépendamment d'une récupération de phase de la porteuse, les coefficients de filtre adaptatif,
pendant une récupération de phase de la porteuse, les coefficients de filtre adaptatif sont mis à jour en utilisant des signaux d'erreur dérivés du premier algorithme,
un signal de blocage de porteuse est produit lorsqu'une erreur de phase de porteuse d'une sortie de signal filtré de l'égaliseur adaptatif (60) atteint une valeur de seuil indicatrice d'une récupération de phase de porteuse, et
le second algorithme de mise à jour du coefficient est sélectionné à la place du premier algorithme de mise à jour du coefficient en réponse au signal de blocage de porteuse.

2. Procédé suivant la revendication 1, caractérisé en ce qu'il comprend les étapes supplémentaires de:

surveiller l'erreur de phase pendant le fonctionnement de l'égaliseur adaptatif (60), et
revenir au premier algorithme s'il est déterminé, pendant l'étape de surveillance, que ladite erreur de phase ne satisfait plus au seuil susdit.

3. Procédé suivant la revendication 1 ou 2, caractérisé en ce que le premier algorithme est un algorithme de compensation à récupération automatique.

4. Procédé suivant la revendication 3, caractérisé en ce que l'algorithme de compensation à récupération automatique est un algorithme à module constant.

5. Procédé suivant l'une des revendications précédentes, caractérisé en ce que le second algorithme est un algorithme dirigé par une décision.

6. Procédé suivant l'une des revendications précédentes, caractérisé en ce que la valeur de seuil est atteinte lorsqu'au moins un pourcentage minimal d'échantillons du signal filtré, pris pendant un temps, tombe dans une plage prédéterminée.

7. Procédé suivant la revendication 6, caractérisé en ce que

le signal de données démodulé comprend des cordonnées représentant une configuration de constellation à N points pour un signal modulé en amplitude en quadrature de N bits démodulés, et
la plage comprend une pluralité de zones fixes séparées, chaque zone enfermant un des points de la configuration en constellation.

8. Procédé suivant la revendication 7, caractérisé en ce que chacune des zones fixes séparées comprend une ellipse entourant un des points de la configuration en constellation, chaque ellipse étant alignée sur un rayon correspondant qui s'étend depuis une origine de la configuration en constellation jusqu'au point que l'ellipse entoure.

9. Système de compensation pour un récepteur de communications, le système comprenant:

une boucle de récupération de porteuse (56) dans laquelle un signal de données non compensé est démodulé,
et un égaliseur adaptatif (60) pour filtrer le signal de données démodulé en utilisant des coefficients de filtre adaptatif,
l'égaliseur adaptatif (60) étant situé dans la boucle de récupération de porteuse (56),
l'égaliseur adaptatif (60) mettant à jour les coefficients précités de filtre adaptatif en utilisant des signaux d'erreur dérivés d'un premier algorithme ou en utilisant des signaux d'erreur dérivés d'un second algorithme plus efficace au lieu du premier algorithme de mise à jour de coefficients,

caractérisé en ce que:

le premier algorithme met à jour, indépendamment d'une récupération de phase de la porteuse, les coefficients de filtre adaptatif,
l'égaliseur adaptatif (60) met à jour les coefficients de filtre adaptatif pendant une récupération de phase de porteuse en utilisant des signaux d'erreur dérivés du premier algorithme,
un générateur de blocage (78) est prévu pour produire un signal de blocage de porteuse lorsqu'une erreur de phase de porteuse d'un signal filtré, délivré par l'égaliseur adaptatif (60), atteint une valeur de seuil indicatrice d'une récupération de phase de porteuse,
et l'égaliseur adaptatif (60) sélectionne le second algorithme de mise à jour de coefficient au lieu du premier algorithme de mise à jour de coefficient en réponse au signal de blocage de porteuse.

10. Système suivant la revendication 9, caractérisé en ce que l'égaliseur adaptatif (60) comprend un filtre adaptatif (70) et un générateur de signal d'erreur (72) raccordé pour recevoir des données filtrées en provenance du filtre adaptatif (70) précité, le générateur de signal d'erreur produisant des signaux d'erreur suivant le premier ou le second algorithme, et des moyens (74) qui répondent auxdits signaux d'erreur en vue de mettre à jour les coefficients de filtre adaptatif précités.

11. Système suivant la revendication 10, caractérisé en ce que:

une boucle de récupération de porteuse comprend un démodulateur (58) et un détecteur de phase (76) raccordés pour recevoir le signal filtré délivré par l'égaliseur adaptatif (60) précité et pour fournir un premier signal d'erreur de phase en vue de commander le démodulateur (58), et
le générateur de blocage reçoit un second signal d'erreur de phase en provenance dudit détecteur de phase (76), en vue de produire le signal de blocage de porteuse lorsque le second signal d'erreur de phase satisfait à un seuil.

12. Système suivant la revendication 9, caractérisé en ce que le générateur de signal d'erreur (72) com-

prend une mémoire mémorisant un premier ensemble de signaux d'erreur calculés en utilisant le premier algorithme et un second ensemble de signaux d'erreur calculés en utilisant le second algorithme.

13. Système suivant la revendication 12, caractérisé en ce que les données filtrées et le signal de blocage de porteuse sont utilisés pour adresser ladite mémoire afin de délivrer des signaux d'erreur.

14. Système suivant l'une des revendications 9 à 13, caractérisé en ce que le premier algorithme est un algorithme de compensation à récupération automatique.

15. Système suivant la revendication 14, caractérisé en ce que l'algorithme de compensation à récupération automatique est un algorithme à module constant.

16. Système suivant l'une des revendications 9 à 15, caractérisé en ce que le second algorithme est un algorithme dirigé par décision.

17. Système suivant l'une des revendications 9 à 16, caractérisé en ce que le seuil d'erreur de phase est satisfait lorsqu'au moins un pourcentage minimal d'échantillons desdites données filtrées prises pendant un temps tombe dans une plage prédéterminée.

18. Système suivant la revendication 17, caractérisé en ce que

le signal de données démodulé comprend des coordonnées représentant une configuration de constellation à N points pour un signal modulé en amplitude en quadrature de N bits démodulés et,

la plage comprend une pluralité de zones fixes séparées, chacune renfermant un des points de la configuration en constellation.

19. Système suivant la revendication 16, caractérisé en ce que chacune des zones fixes séparées comprend une ellipse entourant un des points de la configuration en constellation, chaque ellipse étant alignée sur un rayon correspondant qui s'étend depuis une origine de la configuration en constellation jusqu'au point que l'ellipse entoure.

20. Système suivant la revendication 9, caractérisé en ce qu'il comprend:

un filtre adaptatif (70) pour filtrer des données non compensées représentatives de coordonnées dans une configuration en constellation,
un générateur de signal d'erreur (72) pour convertir des données filtrées en provenance du filtre en des signaux d'erreur sur base d'un premier ou d'un second algorithme,
des moyens (74) raccordés pour recevoir des signaux d'erreur délivrés par le générateur de signal d'erreur (72) en vue de mettre à jour des coefficients pour le filtre adaptatif (70),
un détecteur de phase (76) pour convertir des données filtrées, en provenance du filtre (70), en signaux d'erreur de phase, et
le générateur de blocage (78) répondant aux signaux d'erreur de phase précités pour commander le générateur de signal d'erreur (72) afin de fournir des signaux d'erreur suivant le premier algorithme lorsqu'une erreur de phase représentée par lesdits signaux d'erreur de phase est au dessus d'un seuil prédéterminé et afin de fournir des signaux d'erreur suivant le second algorithme lorsque l'erreur de phase est en dessous du seuil prédéterminé précité.

21. Système suivant la revendication 20, caractérisé en ce que le générateur de signal d'erreur (72) comprend une table de consultation contenant des données de signal d'erreur calculées selon le premier et le second algorithme et adressés par les données filtrées précitées et par les moyens de commande susdit pour délivrer lesdits signaux d'erreur.

22. Système suivant la revendication 20 ou 21, caractérisé en ce que le détecteur de phase (76) comprend une table de consultation contenant des données d'erreur de phase et adressée par les données filtrées susdites afin de délivrer lesdits signaux d'erreur de phase.

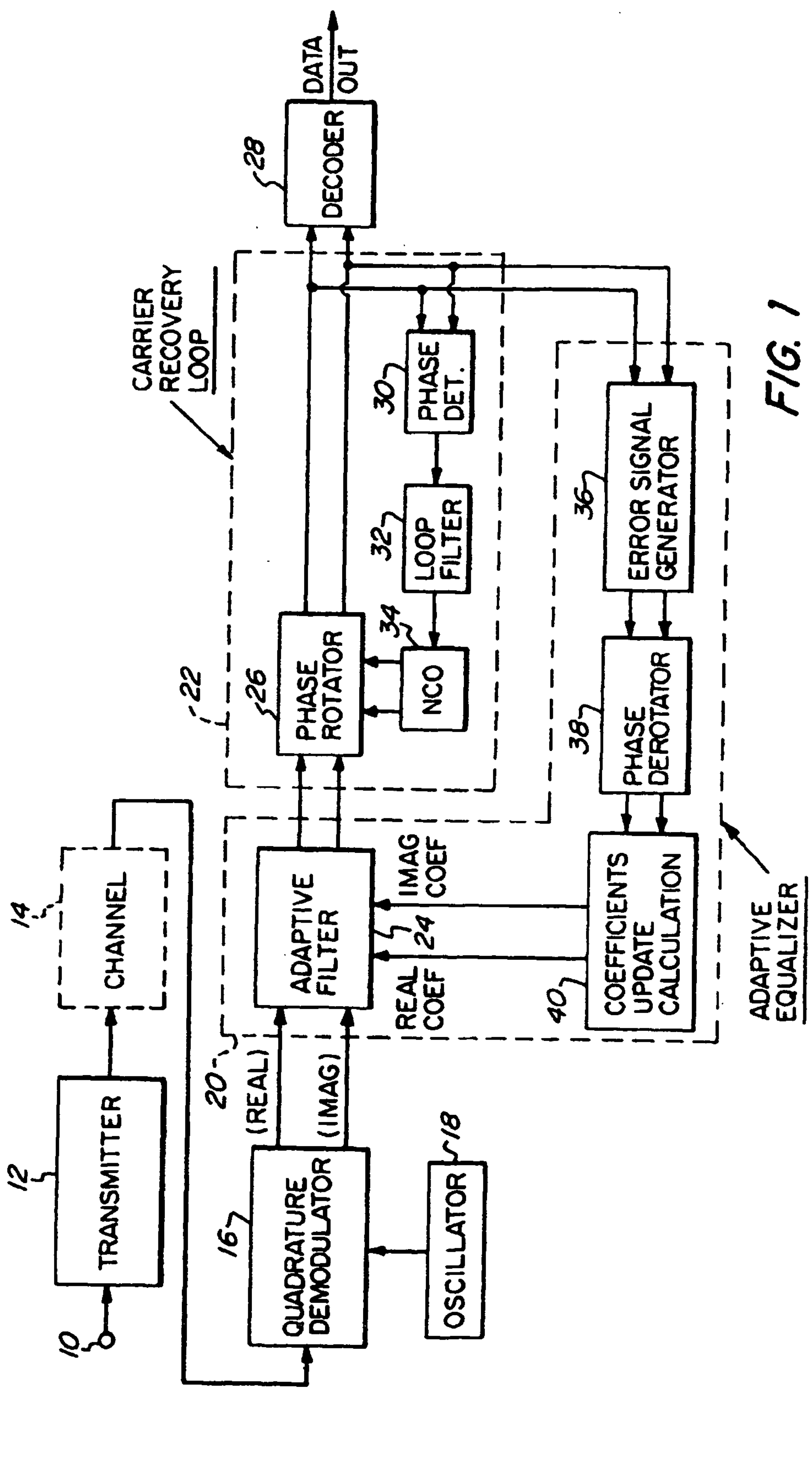

FIG. 1
(PRIOR ART)

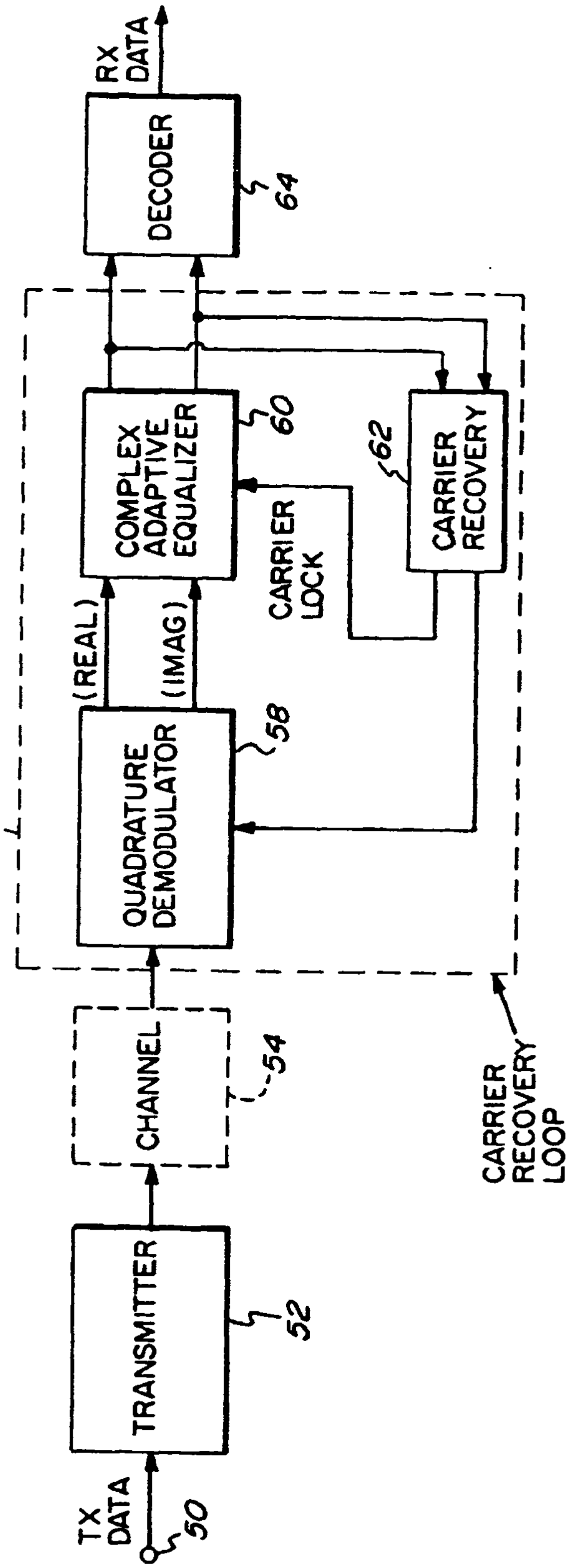
RX DATA
DECODER
64
COMPLEX ADAPTIVE EQUALIZER
60
CARRIER RECOVERY
62
CARRIER LOCK
(REAL)
(IMAG)
QUADRATURE DEMODULATOR
58
56
CHANNEL
54
CARRIER RECOVERY LOOP
TRANSMITTER
52
TX DATA
50

FIG. 2

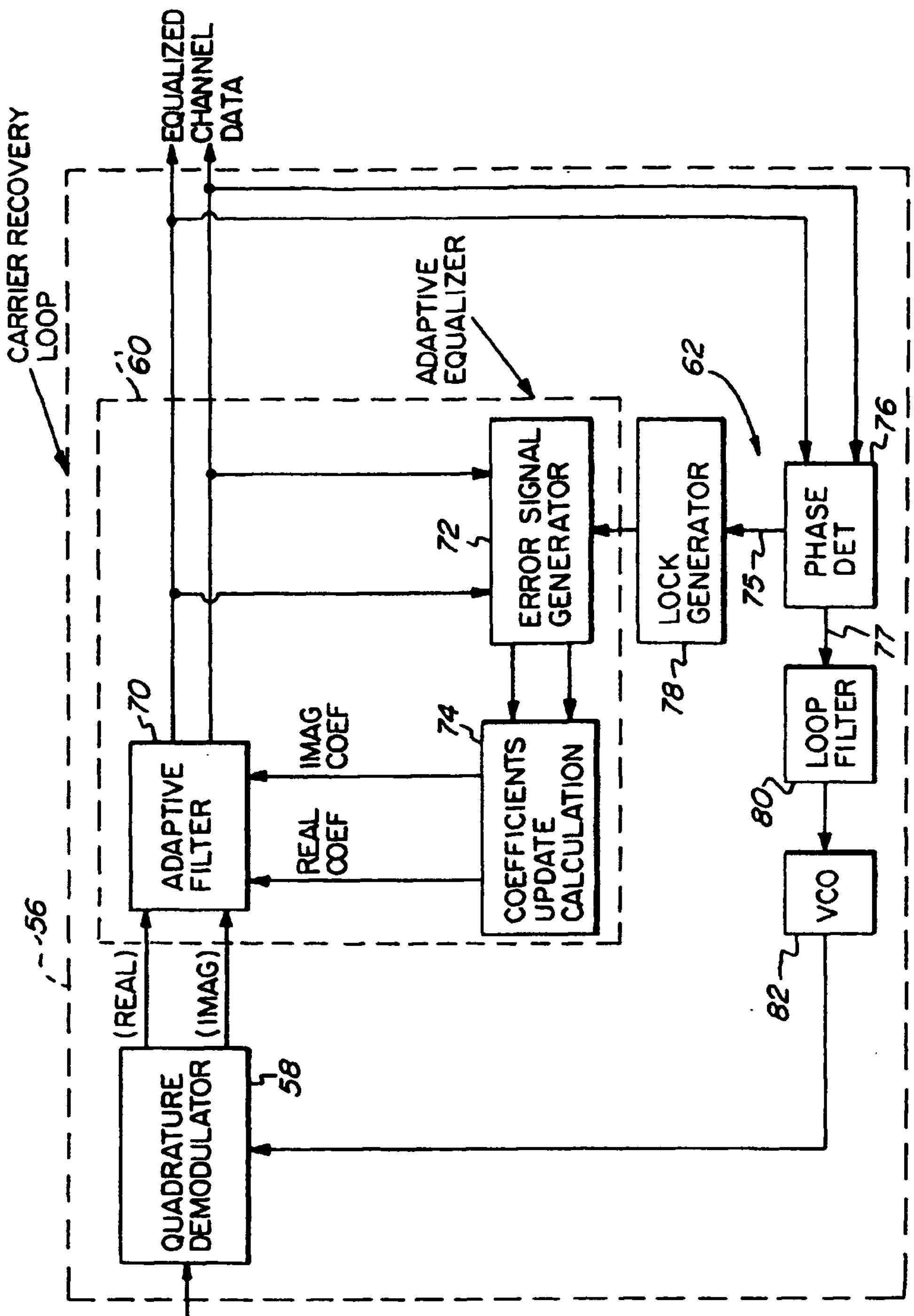
CARRIER RECOVERY LOOP
EQUALIZED CHANNEL DATA
ADAPTIVE EQUALIZER
60
62
76
72
ERROR SIGNAL GENERATOR
LOCK GENERATOR
PHASE DET
75
77
78
70
74
ADAPTIVE FILTER
IMAG COEF
REAL COEF
COEFFICIENTS UPDATE CALCULATION
LOOP FILTER
80
VCO
82
56
(REAL)
(IMAG)
QUADRATURE DEMODULATOR
58
UNEQUALIZED CHANNEL DATA

FIG. 3

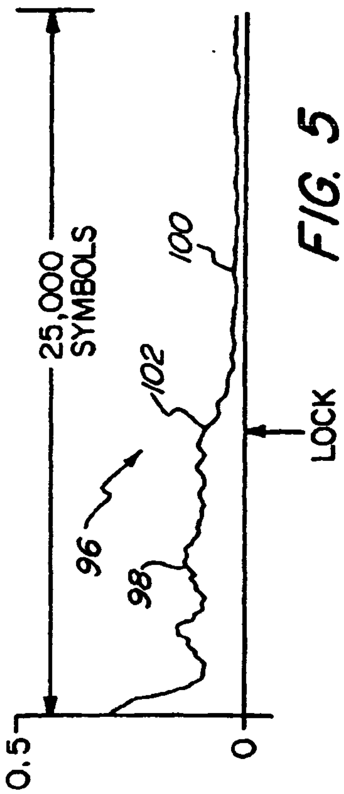

FIG. 5

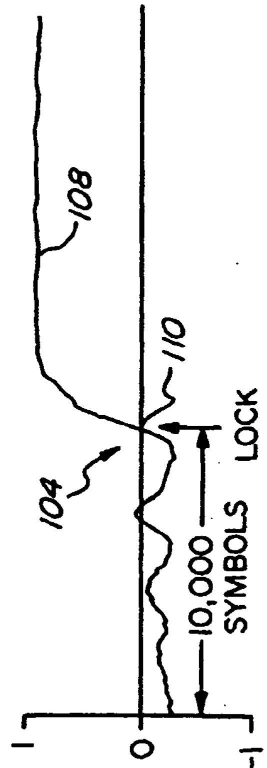

FIG. 6

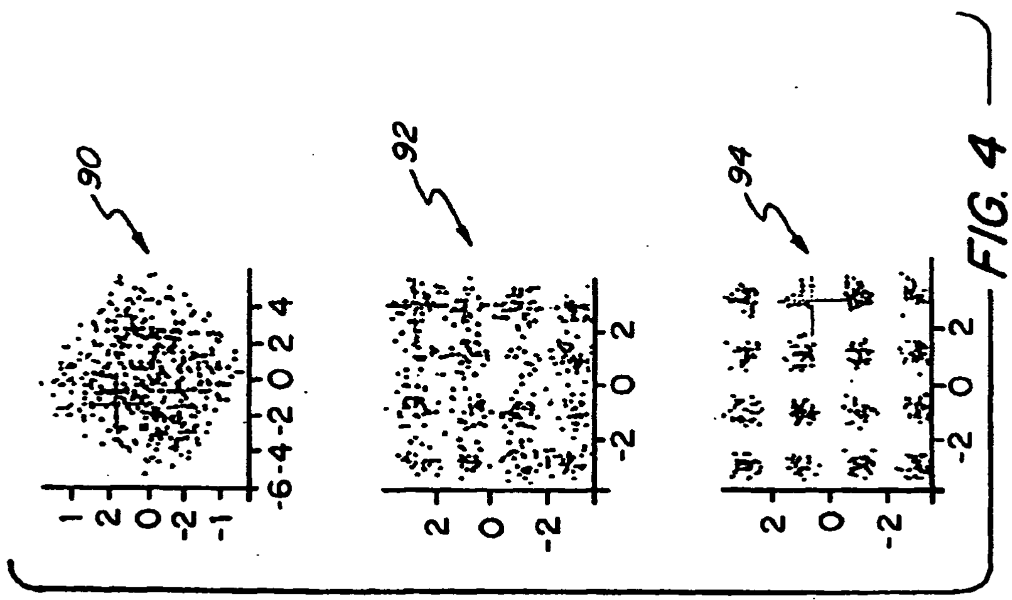

FIG. 4

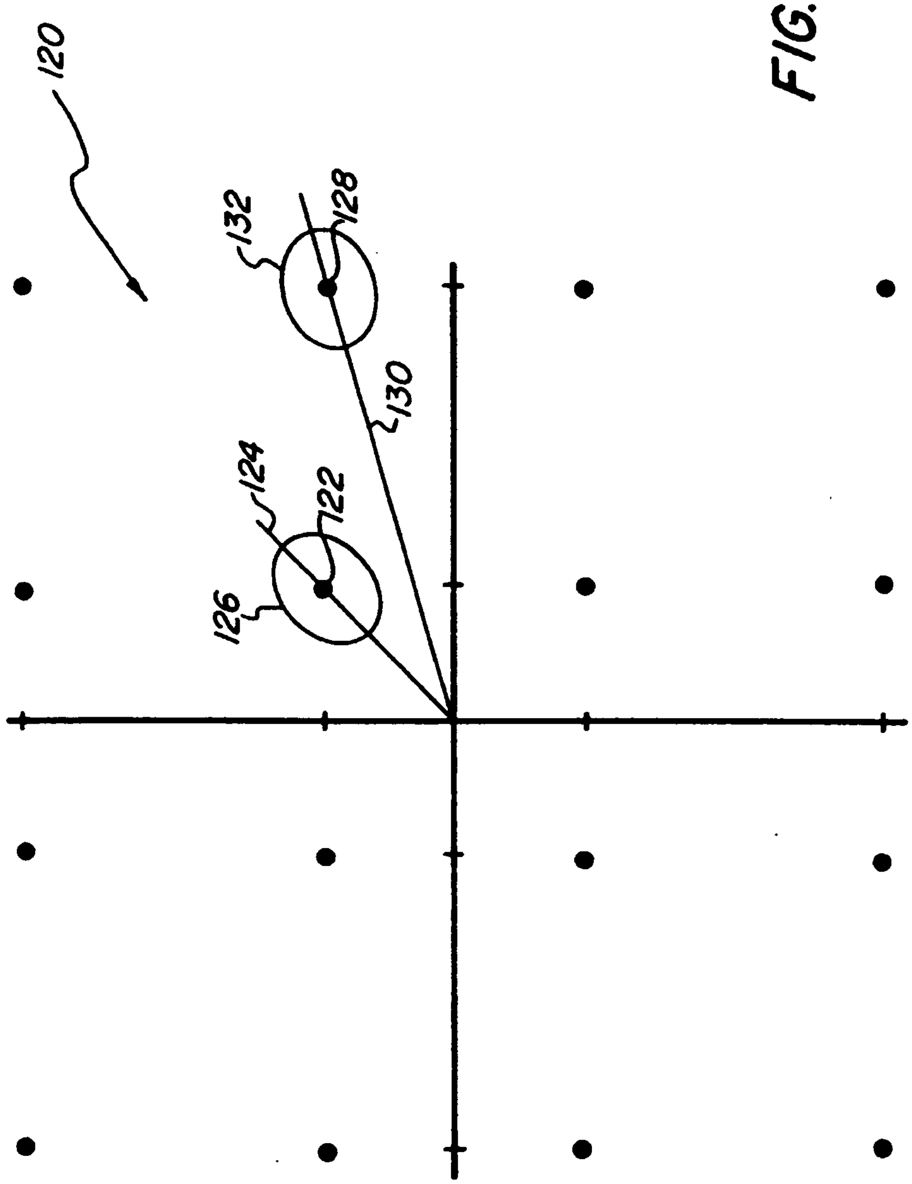

FIG. 7